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(54) **STRUCTURAL AND ACOUSTICAL VIBRATION DAMPENER FOR A ROTATABLE BLADE**

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(51) **Int. Cl.**

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F03D 11/02	(2006.01)
F04D 29/38	(2006.01)
F01D 5/20	(2006.01)
F01D 5/08	(2006.01)
F01D 5/14	(2006.01)
B63H 7/02	(2006.01)

(52) **U.S. Cl.**
USPC .... **416/97 R**; 416/224; 416/241 R

(58) **Field of Classification Search**
USPC 416/224
See application file for complete search history.

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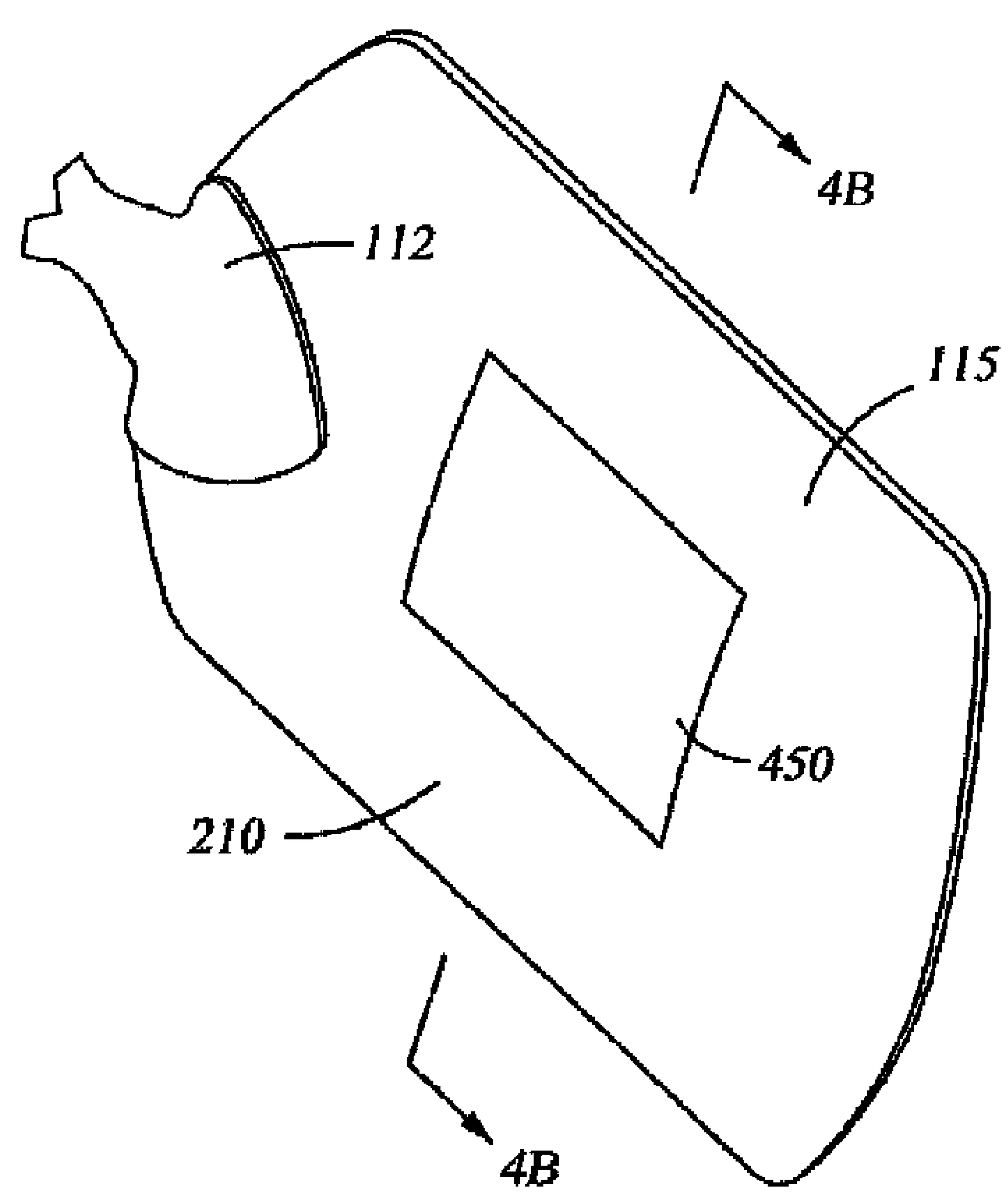
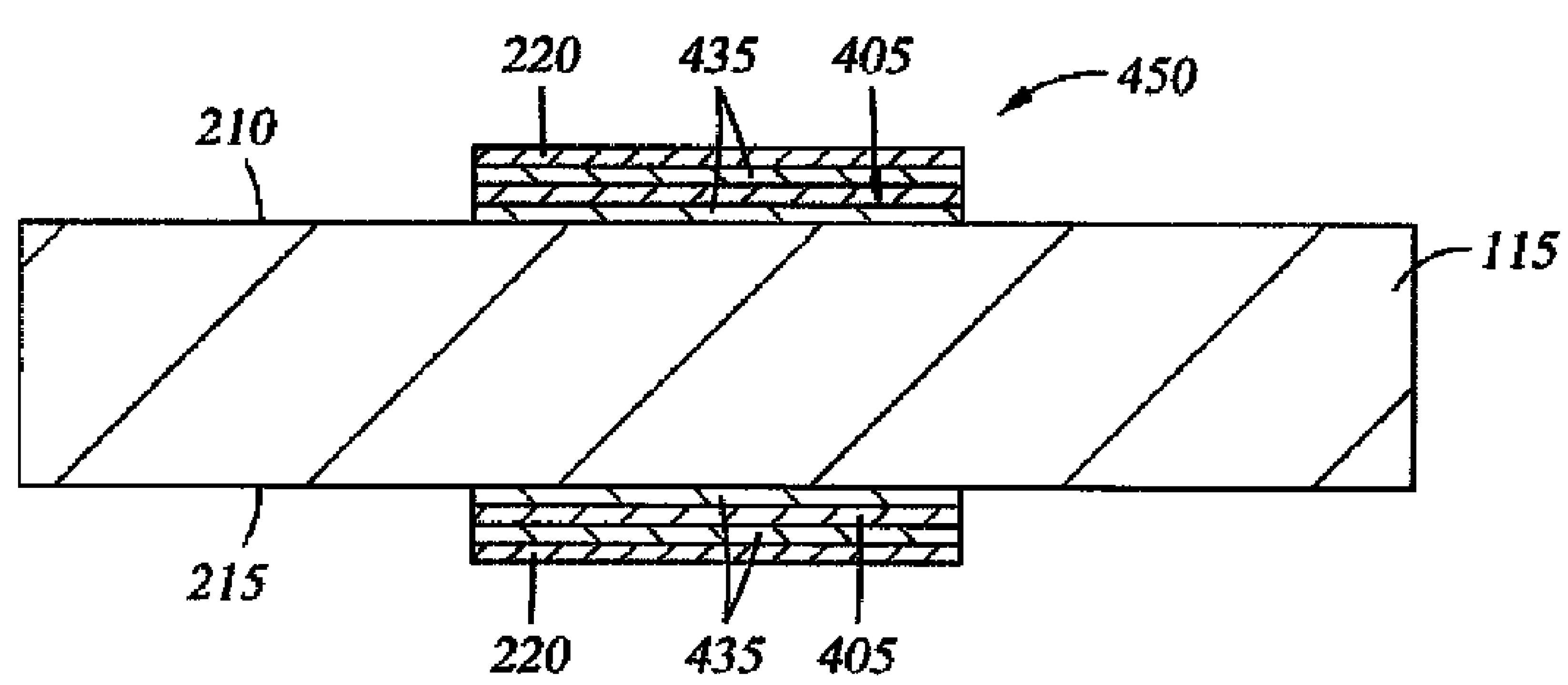
(57) **ABSTRACT**

A structural and acoustical vibration dampener for a rotatable blade comprises a layer of structural/acoustic damping material coupled to at least a portion of the blade. A fan blade comprises a structural layer and a layer of damping material coupled to at least a portion of the structural layer. A method of applying a structural and acoustical vibration dampener to a fan blade comprises identifying a region on the fan blade and securing the structural/acoustical vibration dampener to the fan blade over at least a portion of the region.

24 Claims, 6 Drawing Sheets





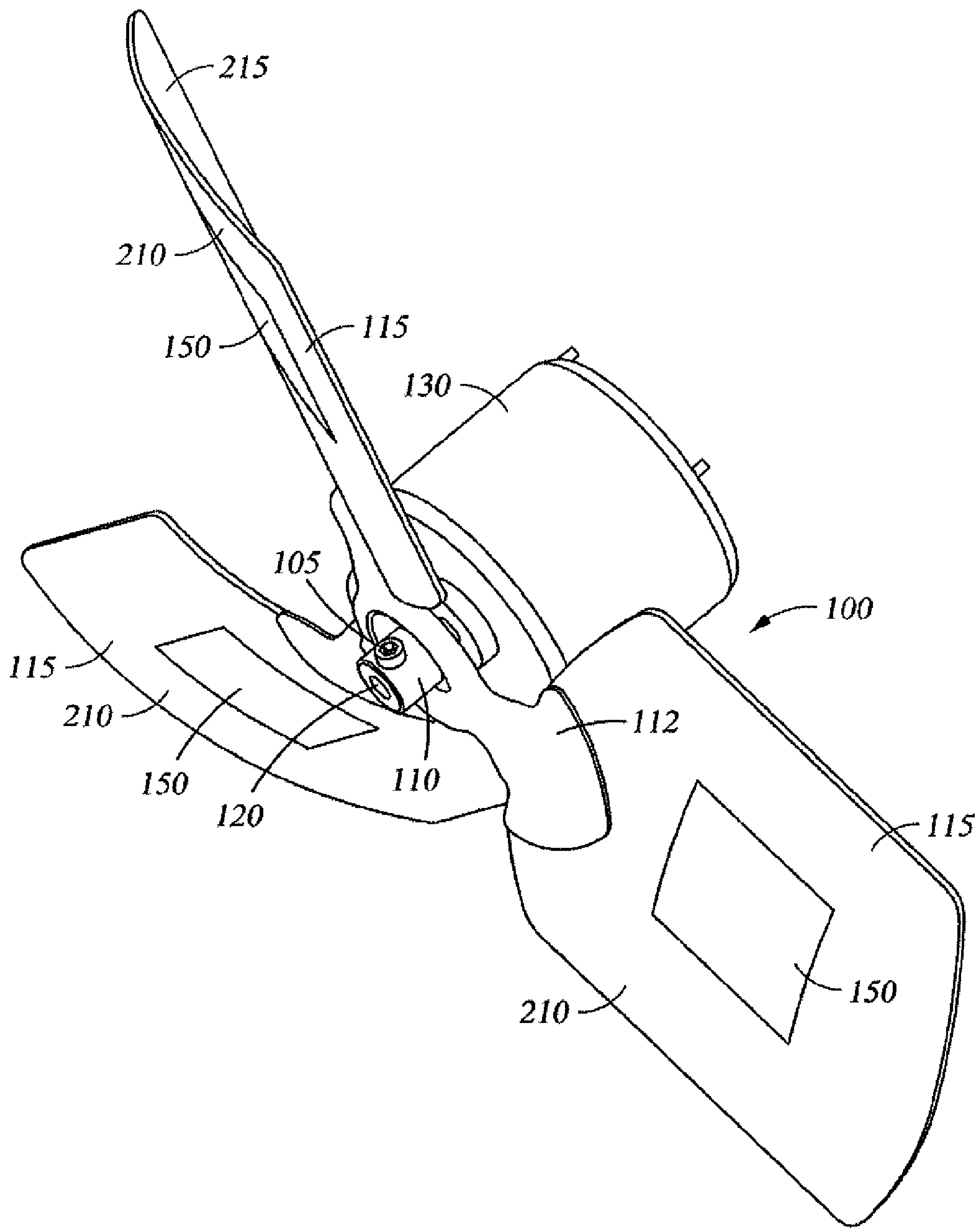
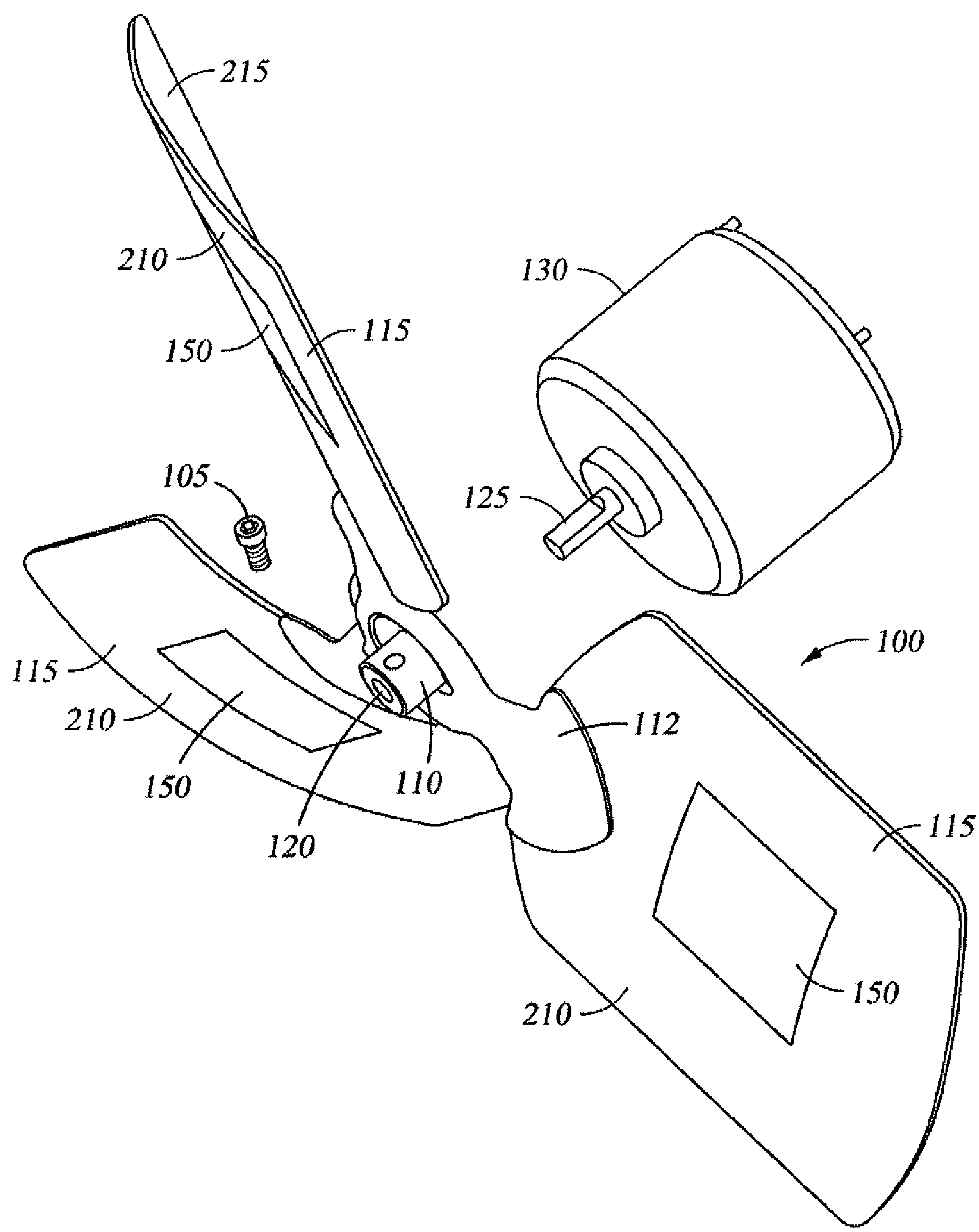


Fig. 1A


215
210
150
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105
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125
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210
150
120
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112
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150
210

Fig. 1B

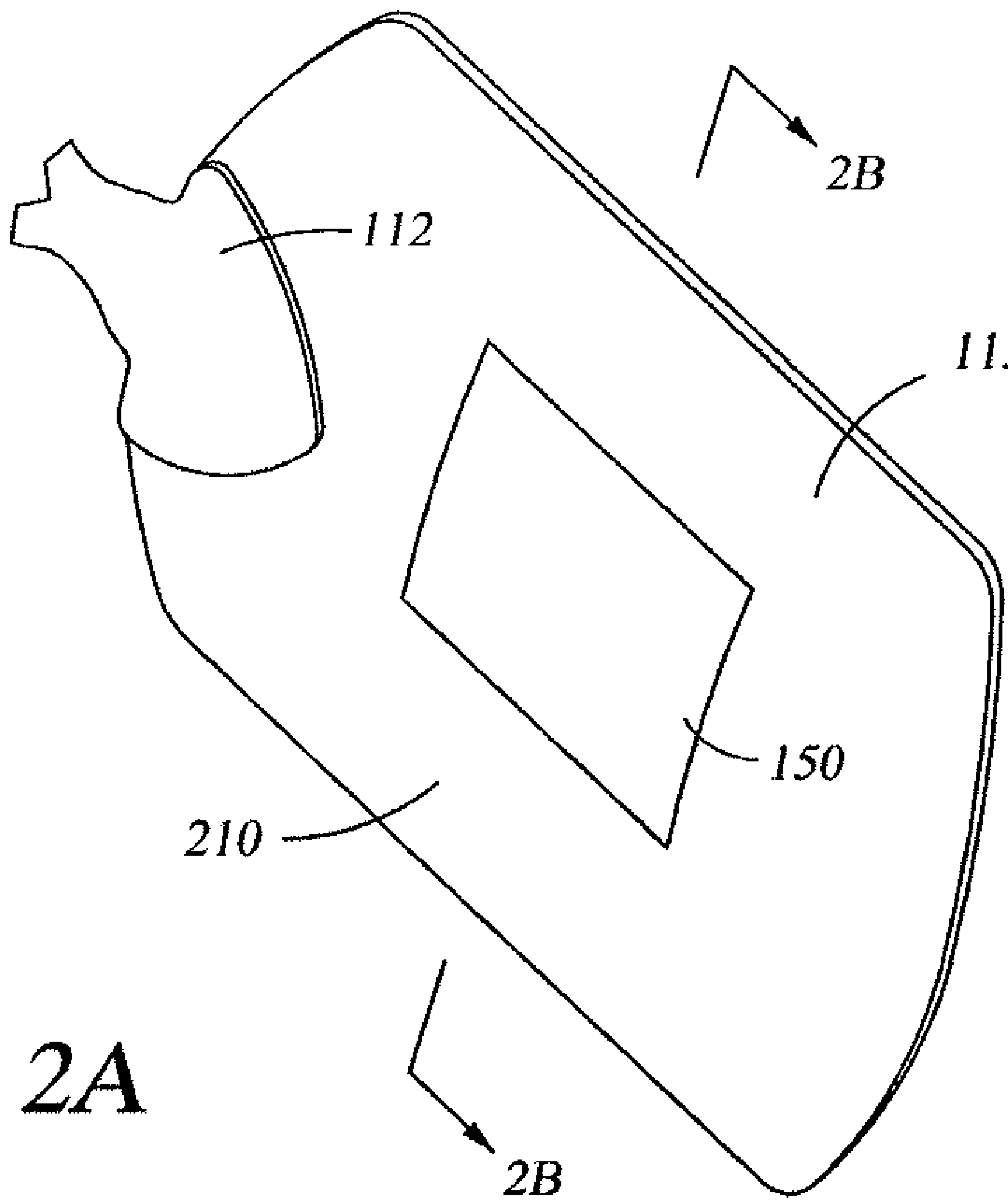

Fig. 2A

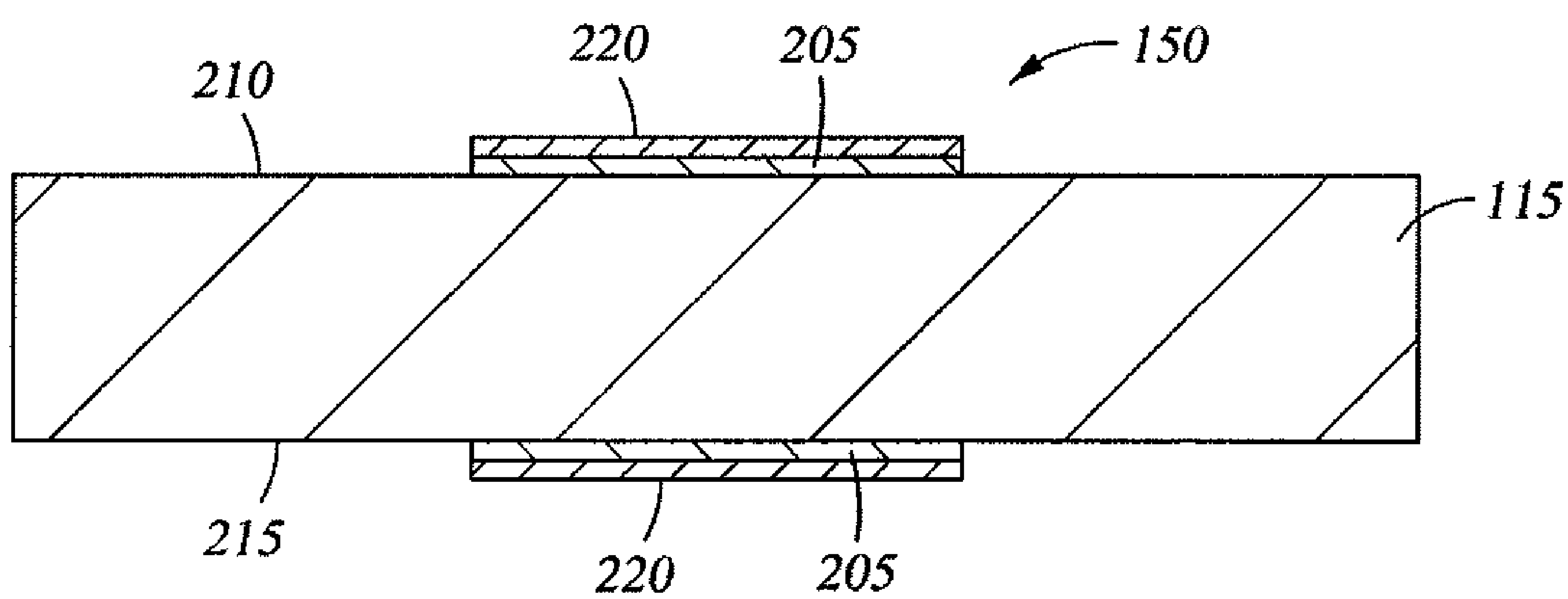

Fig. 2B

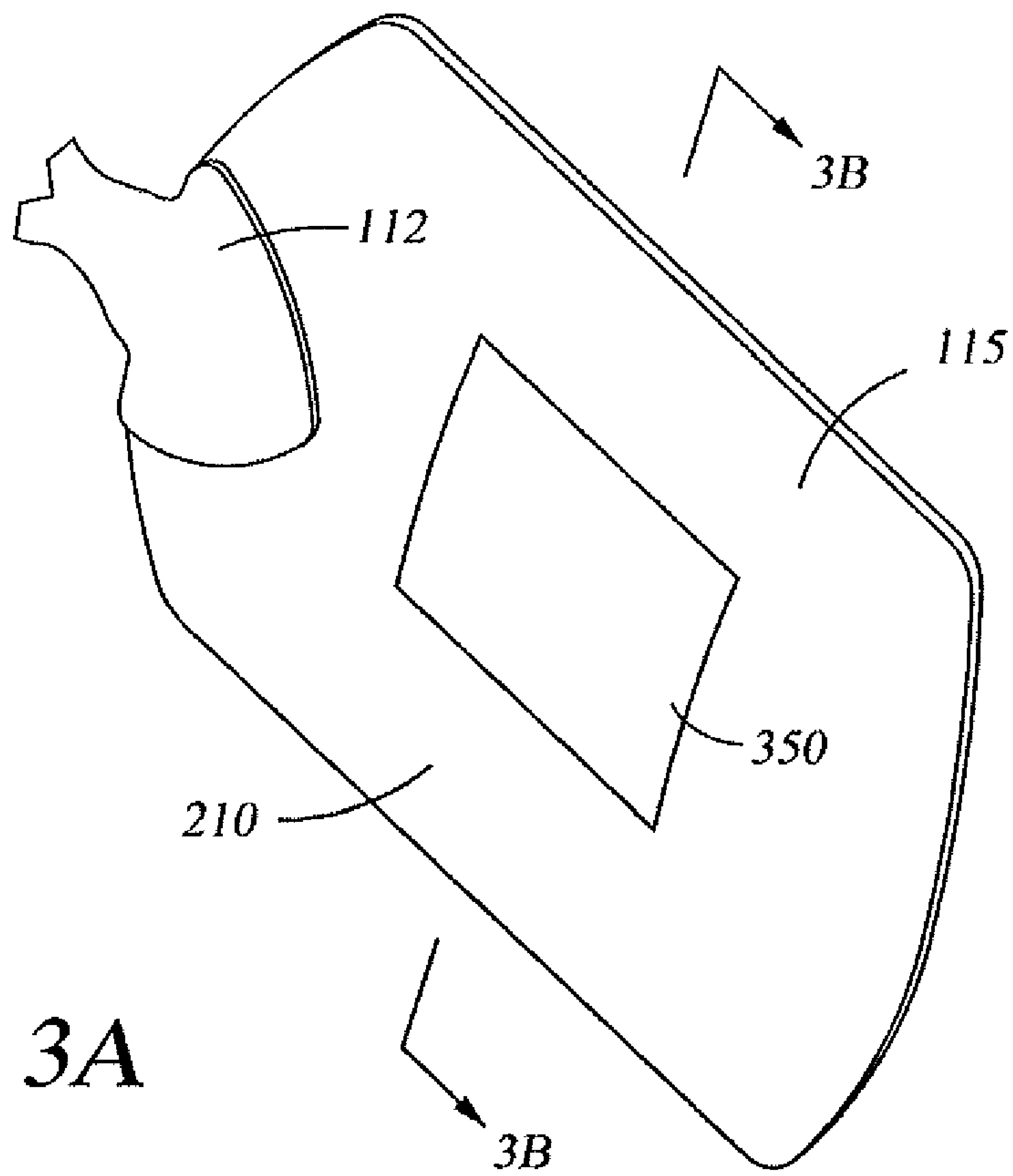

Fig. 3A

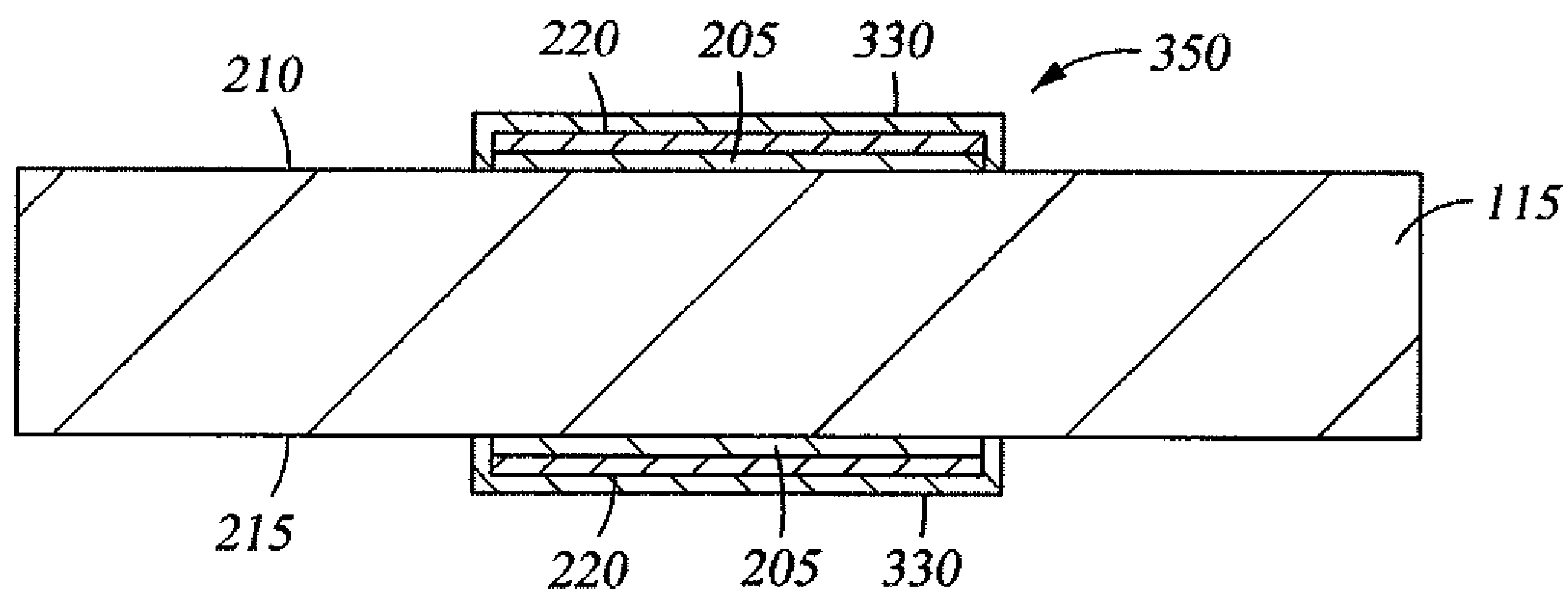

Fig. 3B

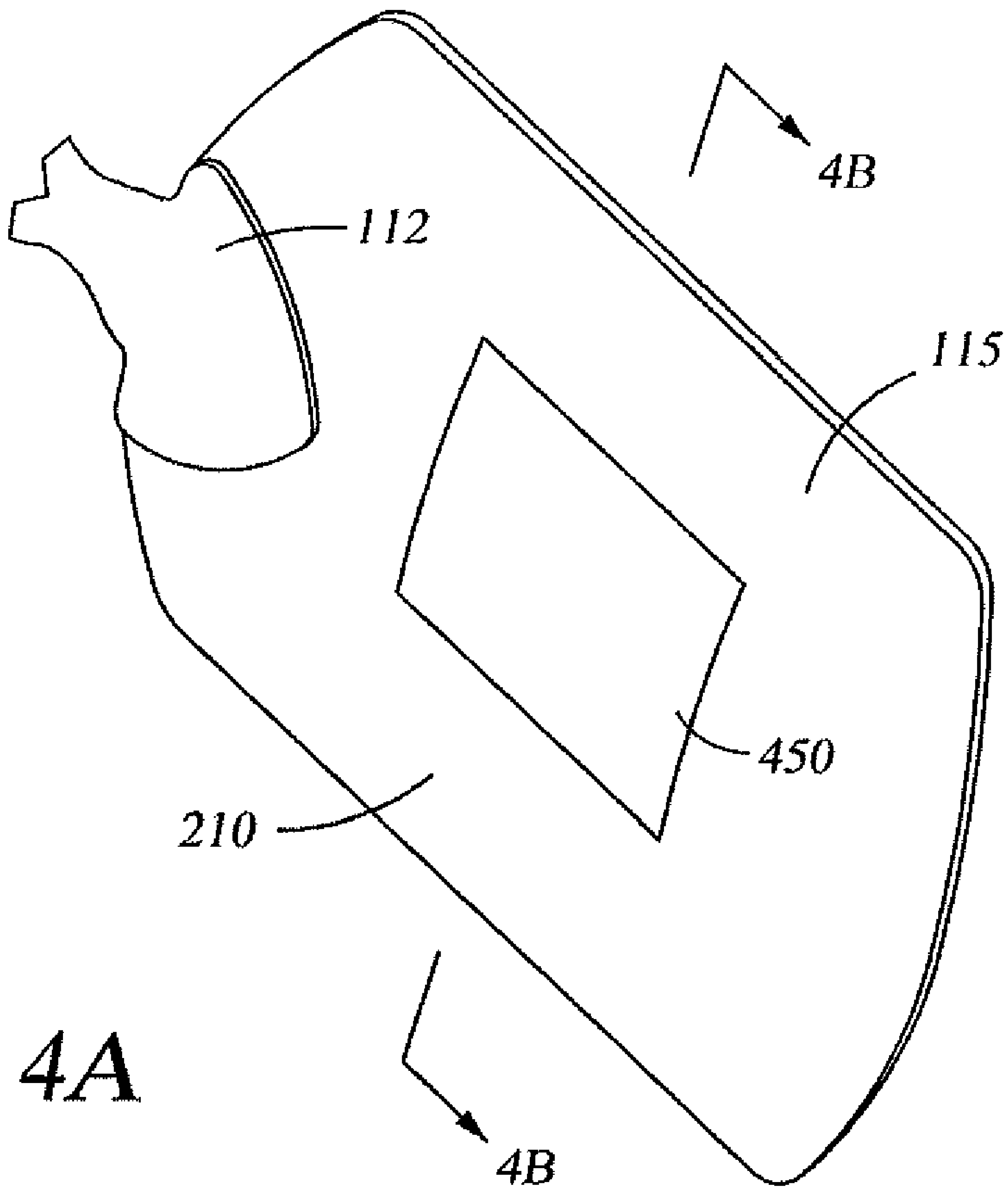

Fig. 4A

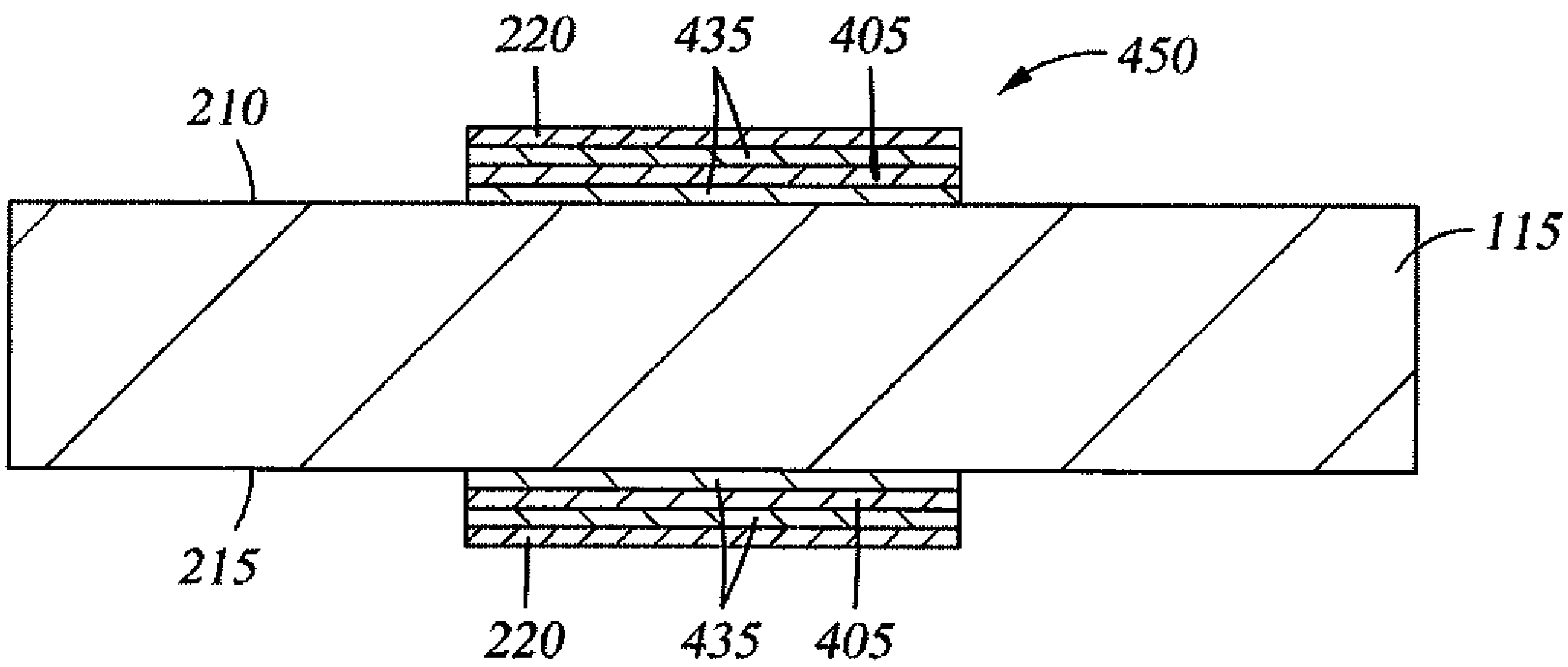

Fig. 4B

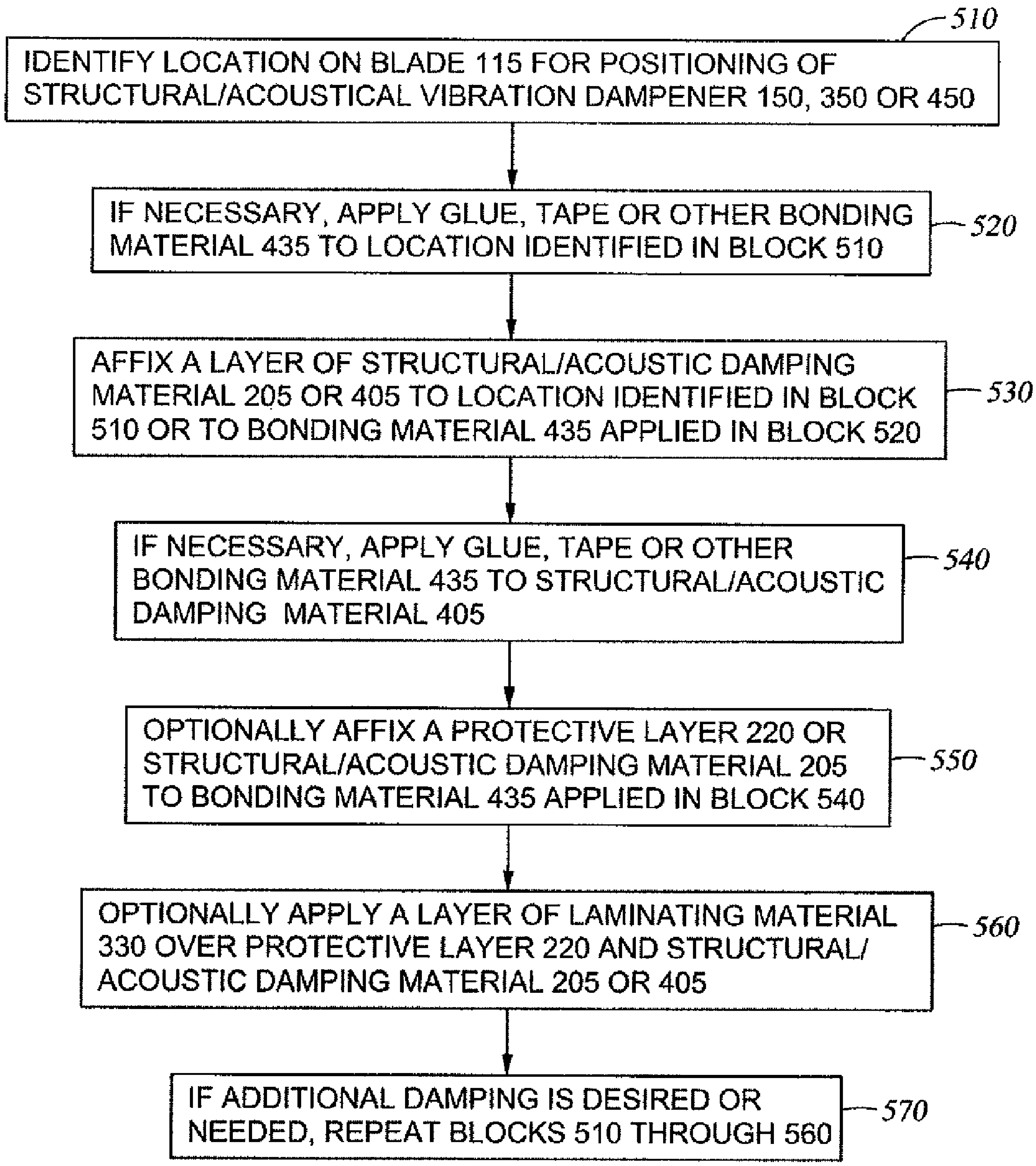
510
IDENTIFY LOCATION ON BLADE 115 FOR POSITIONING OF STRUCTURAL/ACOUSTICAL VIBRATION DAMPENER 150, 350 OR 450
520
IF NECESSARY, APPLY GLUE, TAPE OR OTHER BONDING MATERIAL 435 TO LOCATION IDENTIFIED IN BLOCK 510
530
AFFIX A LAYER OF STRUCTURAL/ACOUSTIC DAMPING MATERIAL 205 OR 405 TO LOCATION IDENTIFIED IN BLOCK 510 OR TO BONDING MATERIAL 435 APPLIED IN BLOCK 520
540
IF NECESSARY, APPLY GLUE, TAPE OR OTHER BONDING MATERIAL 435 TO STRUCTURAL/ACOUSTIC DAMPING MATERIAL 405
550
OPTIONALLY AFFIX A PROTECTIVE LAYER 220 OR STRUCTURAL/ACOUSTIC DAMPING MATERIAL 205 TO BONDING MATERIAL 435 APPLIED IN BLOCK 540
560
OPTIONALLY APPLY A LAYER OF LAMINATING MATERIAL 330 OVER PROTECTIVE LAYER 220 AND STRUCTURAL/ ACOUSTIC DAMPING MATERIAL 205 OR 405
570
IF ADDITIONAL DAMPING IS DESIRED OR NEEDED, REPEAT BLOCKS 510 THROUGH 560

Fig. 5

STRUCTURAL AND ACOUSTICAL VIBRATION DAMPENER FOR A ROTATABLE BLADE

CROSS-REFERENCE TO RELATED APPLICATIONS

Not Applicable.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not Applicable.

BACKGROUND

A typical fan includes a cylindrical hub body with a rotatable blade assembly coupled thereto. The rotatable blade assembly includes a spider with a plurality of arms extending outwardly from a cylindrical central portion connected to the hub body and a plurality of rotatable blades attached to the spider arms. One end of a cylindrical rod, or driveshaft, is disposed within an axial bore through the hub and coupled to the hub body using a set screw or other connection device. A drive unit, such as an electric motor, is coupled to the other end of the driveshaft and operates to transfer power to the hub body in the form of torque by rotating the driveshaft. Due to the coupling of the driveshaft to the hub, and the hub to the blade assembly, rotation of the driveshaft imparts rotation to the hub body and the blades.

Fans are employed in a wide variety of applications and industries, but common design criteria related to fan efficiency and noise requirements, for example, may be employed in many such applications.

SUMMARY OF THE DISCLOSURE

A structural and acoustical vibration dampener for a rotatable blade is disclosed. In an example embodiment, a structural/acoustical vibration dampener for a rotatable blade is disclosed with a layer of structural/acoustic damping material coupled to at least a portion of the blade.

In a second example embodiment, a fan blade is disclosed with a structural layer, and a layer of damping material coupled to at least a portion of the structural layer.

In a third example embodiment, a method of applying a structural/acoustical vibration dampener to a fan blade is disclosed. The method identifies a region on the fan blade, and secures the structural/acoustical vibration dampener to the fan blade over at least a portion of the region.

Thus, the structural/acoustical vibration dampener and associated methods comprise a number of features. The various characteristics described above, as well as other features, will be readily apparent to those skilled in the art upon reading the following detailed description of the embodiments of the disclosure, and by referring to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more detailed description of the various embodiments of the structural and acoustical vibration dampener for a rotatable blade, reference will now be made to the accompanying drawings, wherein:

FIG. **1**A is a schematic perspective view of a fan assembly comprising a representative embodiment of a rotatable blade incorporating a structural/acoustical vibration dampener in accordance with the principles disclosed herein;

FIG. **1**B is a schematic perspective view of the fan assembly of FIG. **1**A, partially separated to depict its various components;

FIG. **2**A is a schematic perspective view of a representative embodiment of a rotatable fan blade with a structural/acoustical vibration dampener;

FIG. **2**B is a schematic cross-sectional view of the fan blade of FIG. **2**A taken along section line **2**B-**2**B;

FIG. **3**A is a schematic perspective view of another representative embodiment of a rotatable fan blade with a structural/acoustical vibration dampener;

FIG. **3**B is a schematic cross-sectional view of the fan blade of FIG. **3**A taken along section line **3**B-**3**B;

FIG. **4**A is a schematic perspective view of yet another representative embodiment of a rotatable fan blade with a structural/acoustical vibration dampener;

FIG. **4**B is a schematic cross-sectional view of the fan blade of FIG. **4**A taken along section line **4**B-**4**B; and

FIG. **5** is a flowchart of one representative method for constructing a rotatable fan blade with a structural/acoustical vibration dampener.

DETAILED DESCRIPTION

Dynamic systems comprise at least three basic characteristics: mass, stiffness and damping. Real structures have distributed mass, stiffness and damping. Hence, real structures have multiple degrees of freedom. When real structures are attached to rotating machinery, such as an electric motor, for example, their vibration and acoustic response will depend on the distribution of their dynamic characteristics and how they interface with the excitation force exerted by the rotating machinery. Without sufficient damping, such an excitation force may cause cyclic deformation of the attached real structure.

During operation of a fan assembly, for example, the rotating drive unit vibrates, in part due to external loads and any imbalances in the motor itself, and this vibration is transferred via an excitation force to the blades through the driveshaft, hub and other components of the fan assembly. This excitation force may cause the blades to vibrate, and any imbalances in the blade assembly may also contribute to blade vibration. Over time, such vibration and the resulting cyclic deformation may shorten the blade life due to the effects of fatigue. Moreover, vibration of the blade assembly and motor may result in acoustic or sound radiation, producing undesirable audible noise that exceeds acceptable levels.

As the frequency of the excitation force approaches any of the natural or resonance frequencies of the blades, vibration of the blades may be amplified, even though the magnitude of the excitation force may not have changed. When the frequency of the excitation force coincides with a natural frequency of the blades, vibration of the blades is maximized. Thus, the blades experience maximum deformation and produce the highest level of acoustic or sound radiation, often resulting in undesirable levels of audible noise. The deformed shape of a blade responding to application of an excitation force at a frequency equal to a natural frequency of the blade is often referred to as its mode shape. When a blade deforms to one of its mode shapes, the blade may experience complete structural failure.

Some methods of reducing vibration, and the associated fatigue and noise, in a fan assembly are to equip the electric motor with a vibration dampener and/or eliminate imbalances in the motor through maintenance and/or offset imbalances in the blade assembly by coupling small weights to one or more of the blades, as is often done to balance residential ceiling fans. Alternatively, the blade structure may be modified to cause a shift in the natural frequencies of the blades away from the frequency of the motor excitation force, such as by viscous dampening, which involves changing the weight or stiffness of the blade. However, these methods may not adequately dampen or reduce fan vibration, and the associated noise, in certain circumstances.

For example, if a drive unit is a variable speed motor without a vibration dampener, then more than one of its variable speeds may produce an excitation force having a frequency equal to a natural frequency of the blades. Such speeds are referred to as critical speeds, and a variable speed motor in a fan assembly may have multiple critical speeds. Thus, it may not be possible to modify the blade structures by viscous dampening so as to shift their natural frequencies sufficiently away from the excitation frequencies of the motor for all of the critical speeds.

The present disclosure relates generally to apparatus and methods for damping vibration of a rotatable blade. More particularly, the present disclosure relates to a structural and acoustical vibration dampener for a rotatable blade, which is susceptible to embodiments of different forms. There are shown in the drawings, and herein will be described in detail, specific embodiments of a structural/acoustical vibration dampener for a rotatable blade and associated methods with the understanding that the disclosure is to be considered representative only and is not intended to limit the apparatus and methods to that illustrated and described herein. In particular, various embodiments of the structural/acoustical vibration dampener are described in the context of a fan blade. However, these components may be used in any application where it is desired to reduce vibration of a rotating blade and the associated audible noise. Thus, a structural/acoustical vibration dampener for a rotatable blade may be utilized in, for example, a turbine or an airboat, as well as a fan. It is to be fully recognized that the different teachings of the embodiments disclosed herein may be employed separately or in any suitable combination to produce desired results.

FIGS. **1**A and **1**B depict schematic perspective views of a fan **100** in assembled and partially disassembled form, respectively; the fan **100** comprising a plurality of blades **115**, where each is a representative embodiment of a fan blade **115** with sides **210**, **215** and with a structural and acoustical vibration dampener **150** affixed to at least one side **210**, **215** thereof. Blades **115** are coupled to a hub **110** by a spider **112**. Hub **110** has an axial bore **120** therethrough, and a driveshaft **125** disposed partially within the axial bore **120** and coupled to the hub **110** by a set screw **105**. Fan **100** further comprises a drive unit **130** coupled to the driveshaft **125** and selectively operable to rotate the driveshaft **125**. Drive unit **130** may comprise an electric motor or another type of motor, for example. In at least one embodiment, drive unit **130** is a variable speed electric rotor motor without a resilient vibration isolator, also referred to as a non-resilient rotor mount. Due to the coupling of the driveshaft **125** and hub **110** via the set screw **105**, rotation of the driveshaft **125** by the drive unit **130** also causes rotation of the hub **110**, the spider **112** and the blades **115**, thereby creating movement of the surrounding air.

FIGS. **2**A and **2**B are schematic perspective and cross-sectional views, respectively, of a single blade **115** with structural/acoustical vibration dampener **150** affixed thereto. Blade **115** may comprise a conventional fan blade formed of any suitable material, such as aluminum, steel, other metals, or plastics. Structural/acoustical vibration dampener **150** may cover only a portion of blade **115**, as shown in FIG. **2**A, on either or both sides **210**, **215** of blade **115**, as shown in FIG. **2**B. Alternatively, structural/acoustical vibration dampener **150** may extend the full length and width of blade **115**, again on either or both sides **210**, **215** of blade **115**. Further, the size and orientation of structural/acoustical vibration dampener **150** may vary from one blade **115** to another within fan **100**. Still further, each blade **115** may comprise more than one structural/acoustical vibration dampener **150**.

As illustrated by FIG. **2**B, in an embodiment, structural/acoustical vibration dampener **150** comprises a layer of structural and acoustic damping material **205**, shown coupled to each side **210**, **215** of blade **115**. Structural/acoustic damping material **205** comprises a vibration damping, or energy absorbing, material, and in some embodiments may comprise an adhesive, a resin, an epoxy, a glue, a tape or a paint that may be directly applied to sides **210**, **215** of blade **115** without the need for a separate bonding material. Further, structural/acoustic damping material **205** may comprise viscoelastic material. A suitable viscoelastic damping material is available from MSC. In an embodiment, the structural/acoustic damping material **205** cures over time at ambient temperature or in response to the application of heat.

Structural/acoustical vibration dampener **150** may optionally further comprise a protective layer **220** of material, such as foil or other suitable material, that overlies the structural/acoustic damping material **205**. In some embodiments where the protective layer **220** comprises foil, the foil is aluminum. If the structural/acoustic damping material **205** has a pressure sensitive, adhesive property, protective layer **220** may adhere directly to structural/acoustic damping material **205** without the need for glue or another similar bonding material. In an embodiment, the structural/acoustic vibration dampener **150** is a specially formulated pressure sensitive, adhesive (PSA) foil-tape consisting of a structural/acoustic damping material **205** overlaid by a foil protective layer **220**. One suitable PSA foil tape is Avery Denison FT0816, and suitable PSA tapes are also available from 3M and other suppliers.

The size and positioning of each structural/acoustical vibration dampener **150** on a blade **115** is dictated by the degree of damping needed, or desired, during operation of fan **100**. Notably, a suitable, but coarse, damping technique is to extend structural/acoustical vibration dampener **150** the full length and width of blade **115**. However, to determine more particularly the degree of damping needed, the natural or resonance frequencies and their corresponding mode shapes for blade **115**, in the absence of any structural/acoustical vibration dampener **150**, are first identified, either through testing or through experimental or analytical modal analysis. A mode shape, also known as a deflection shape, is the deformed shape of blade **115** resulting from the application of an excitation force, such as that provided by motor vibration, at a frequency equal to a corresponding natural frequency. Blade **115** may have one or more natural frequencies and a mode shape corresponding to each. By identifying and examining each mode shape of blade **115**, the location(s) of maximum vibration, or maximum deflection, for blade **115** may be identified. In the locations of maximum vibration, a portion of blade **115** deflects in a first direction and an adjacent portion of blade **115** approximately simultaneously deflects in a second direction that is opposite and out of phase with the first direction. For example, in one representative location of maximum deflection, a portion of blade **115** may deflect upwardly while an adjacent portion of blade **115** approximately simultaneously deflects downwardly relative to a horizontal plane.

Once identified, a structural/acoustical vibration dampener **150** may be positioned at each of these maximum deflection locations to overlap adjacent portions of the blade **115** that vibrate or deform out of phase with one another. In other words, each structural/acoustical vibration dampener **150** so positioned couples a region of high blade vibration in a first direction to a region of high blade vibration in a second direction that is out of phase with the first direction, thereby providing damping to the region. By positioning structural/acoustical vibration damnpener(s) **150** in this manner, maximum blade vibration, and thus deformation, is reduced by the energy-absorbing ability of structural/acoustic damping material **205**. Hence, during operation of fan **100**, the magnitude of vibrations experienced by blade **115** is reduced. Accordingly, the magnitude of sound pressure waves produced by the blade vibrations is also reduced, yielding a reduction in the level of noise generated by the vibration of blade **115**, and therefore fan **100**.

FIGS. **3**A and **3**B are schematic perspective and cross-sectional views, respectively, of another representative fan blade **115** with a structural/acoustical vibration dampener **350**. Structural/acoustical vibration dampener **350** may be similar in all respects to structural/acoustical vibration dampener **150** except that structural/acoustical vibration dampener **350** further comprises a laminate layer **330** disposed over each protective layer **220** to provide additional protection to both protective layer **220** and the underlying structural/acoustic damping material **205** from the surrounding environment. In some embodiments, laminate layer **330** comprises plastic.

FIGS. **4**A and **4**B are schematic perspective and cross-sectional views, respectively, of another representative fan blade **115** with a structural and acoustical vibration dampener **450**. Structural/acoustical vibration dampener **450** may be similar in all respects to structural/acoustical vibration dampener **150** except that structural/acoustic damping material **405** does not comprise an adhesive property. As such, glue, tape or other similar bonding material **435** may be applied between sides **210**, **215** of blade **115** and the adjacent layers of structural/acoustic damping material **405** and between the layers of structural/acoustic damping material **405** and the adjacent protective layers **220** to affix all layers of the structural/acoustical vibration dampener **450** to blade **115**. As described above in reference to structural/acoustical vibration dampener **350** and shown in FIG. **3**B, structural/acoustical vibration dampener **450** may optionally further comprise a laminate layer **330** over protective layer **220**.

FIG. **5** illustrates one embodiment of a method for constructing a fan blade **115** with a structural/acoustical vibration dampener **150**, **350**, or **450**. The method begins at block **510** by identifying a location on blade **115** where a structural/acoustical vibration dampener **150**, **350** or **450** may be applied to reduce blade vibration. As described above, the mode shape for each natural frequency of blade **115**, in the absence of any structural/acoustical vibration dampener **150**, **350** or **450**, is identified through testing or analysis and examined to determine the region(s) of maximum blade vibration, or deformation. These regions suggest the most effective locations for placement of structural/acoustical vibration dampener(s) **150**, **350** or **450** for the purpose of noise reduction. For a region of maximum blade deformation identified through testing or analysis, the location on blade **115** for placement of structural/acoustical vibration dampener(s) **150**, **350** or **450** is such that structural/acoustical vibration dampener **150**, **350** or **450**, when coupled to blade **115**, overlaps adjacent portions of the blade **115** that vibrate or deform out of phase with one another.

At block **520**, glue, tape or other bonding material **435** may be applied to the location identified in block **510** if the structural/acoustical vibration dampener comprises a structural acoustic damping material that does not have an adhesive property, such as structural/acoustical vibration dampener **450**. Next, at block **530**, a layer of structural/acoustic damping material **205** or **405** is applied to the location identified in block **510** or to the bonding material **435** of block **520**, respectively, by application of pressure. Once applied, structural/acoustic damping material **205** or **405** ties or couples adjacent portions of the blade **115** that vibrate or deform out of phase with one another. If necessary, glue, tape or other bonding material **435** is applied to structural/acoustic damping material **405** of structural/acoustical vibration dampener **450** at block **540**. A protective layer **220** of foil or other suitable material may optionally be overlaid onto structural/acoustic damping material **205** or bonding material **435** covering structural/acoustic damping material **405** by application of pressure at block **550**. Lastly, a layer of laminating material **330** may be optionally applied over protective layer **220** and structural/acoustic damping material **205** or **405**. The method is repeated as necessary to achieve the desired degree of damping for blade **115**.

A structural/acoustical vibration dampener in accordance with the principles disclosed herein should diminish the magnitude of vibrations that a fan blade would otherwise experience in the absence of the structural/acoustical vibration dampener. As a result, the magnitude of sound pressure waves produced by the blade vibrations should also be reduced, which would thereby reduce the level of noise produced by the blades. In addition to noise reduction, the effects of fatigue to the blade would also be reduced, providing a longer service life for the fan.

While various embodiments of a structural/acoustical vibration dampener and methods of constructing a rotatable blade with a structural/acoustical vibration dampener have been shown and described, modifications thereof can be made by one skilled in the art without departing from the spirit or teaching of this disclosure. The embodiments described herein are representative only and are not limiting. Many variations and modifications of the apparatus and methods are possible and are within the scope of the disclosure. Accordingly, the scope of protection is not limited to the embodiments described herein, but is only limited by the claims which follow, the scope of which shall include all equivalents of the subject matter of the claims.

What is claimed is:

1. A structural/acoustical vibration dampener for a rotatable blade comprising:
- a layer of structural/acoustic damping material disposed on a single external surface of the blade, wherein the structural/acoustic damping material covers at least a portion of the external surface of the blade;
- wherein the structural/acoustic damping material comprises a viscoelastic material.

2. The structural/acoustical vibration dampener of claim **1**, further comprising:
- a layer of protective material overlaying the structural/acoustic damping material such that the structural/acoustical damping material is disposed between the layer of protective material and the external surface.

3. The structural/acoustical vibration dampener of claim **1**, wherein the structural/acoustic damping material comprises an adhesive property.

4. The structural/acoustical vibration dampener of claim **1**, wherein the structural acoustic damping material comprises paint.

5. The structural/acoustical vibration dampener of claim **1**, wherein the structural/acoustic damping material cures at ambient temperature.

6. The structural/acoustical vibration dampener of claim **1**, wherein the structural/acoustic damping material cures in response to the application of heat.

7. The structural/acoustical vibration dampener of claim **2**, wherein the structural/acoustical vibration dampener comprises tape.

8. The structural/acoustical vibration dampener of claim **2**, wherein the protective material is foil.

9. The structural/acoustical vibration dampener of claim **8**, wherein the foil is aluminum.

10. The structural/acoustical vibration dampener of claim **2**, further comprising a laminate layer overlaying the layer of protective material.

11. The structural/acoustical vibration dampener of claim **10**, wherein the laminate layer comprises plastic.

12. A fan blade comprising:

a structural layer defining at least a bottom side and a top side of the fan blade; and

a layer of viscoelastic damping material coupled to the structural layer, wherein the damping material is disposed on at least a portion of a single external surface of the bottom or top side of the fan blade.

13. The fan blade of claim **12**, further comprising:

a layer of protective material;

wherein the layer of damping material is disposed between the structural layer and the layer of protective material.

14. The fan blade of claim **12**, wherein the layer of damping material directly adheres to the structural layer.

15. The fan blade of claim **13**, wherein the layer of damping material directly adheres to the layer of protective material.

16. The fan blade of claim **13**, further comprising a laminate layer overlaying the layer of protective material such that the layer of protective material is disposed between the laminate layer and the layer of damping material.

17. A method of applying a structural/acoustical vibration dampener to a fan blade, comprising:

identifying a region on the fan blade; and

securing the structural/acoustical vibration dampener to a single external surface of the fan blade such that the structural/acoustical vibration dampener extends over at least a portion of the region;

wherein the structural/acoustic damping material comprises a viscoelastic material.

18. The method of claim **17**, wherein the identifying comprises:

determining one or more natural frequencies of vibration of the fan blade;

determining a mode shape corresponding to each natural frequency; and

selecting an area of maximum vibration on the fan blade for at least one mode shape as the region.

19. The method of claim **17**, wherein the structural/acoustical vibration dampener comprises a layer of structural/acoustic damping material and a layer of protective material; and wherein the securing comprises:

adhering the layer of structural/acoustic damping material to the external surface of the fan blade; and

adhering the layer of protective material to the layer of structural/acoustic damping material such that the structural/acoustic damping material is disposed between the layer of protective material and the external surface of the fan blade.

20. The method of claim **17**, further comprising laminating the structural/acoustical vibration dampener.

21. The method of claim **17**, wherein the region on the fan blade experiences at least some deformation and wherein the securing of the structural/acoustical vibration dampener to the fan blade further comprises coupling adjacent portions of the fan blade that deform out of phase with one another.

22. The structural/acoustical vibration dampener of claim **1**, wherein the structural/acoustic damping material extends along the external surface for the full length and width of the blade.

23. The structural/acoustical vibration dampener of claim **1**, further comprising:

another layer of structural/acoustic damping material disposed on an opposing external surface of the blade such that the blade is disposed between each layer of structural/acoustic damping material.

24. The structural/acoustical vibration dampener of claim **10**, wherein the laminate layer surrounds the layer of protective material and the layer of structural/acoustic damping material such that the protective material and the structural/acoustic damping material are enclosed within an interior formed between the laminate layer and the external surface.

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